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EXPERIMENTAL STORAGE OF CALIFORNIA LEMONS IN CONTROLLED ATMOSPHERES

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EXPERIMENTAL STORAGE OF CALIFORNIA LEMONS IN CONTROLLED ATMOSPHERES

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SUMMARY AND CONCLUSIONS

Lemons were stored at 56° F. in various concentrations of oxygen and carbon dioxide.

Carbon dioxide delayed degreening, deepened the color of ripe lemons after long storage, lowered citric acid retention, and at concentrations of 10 percent or higher impaired the flavor of the lemons. A carbon dioxide concentration of 5 percent is probably suitable for lemons. This concentration gives the beneficial effect of delaying degreening somewhat, and thus lengthens the period of marketability, without causing the lemons to become too dark yellow in color or to lose much citric acid.

Dark green lemons successively change to light green, silver, light yellow, and dark yellow or nearly orange color. The last-named color is an indication of senescence and should be avoided to retain desirable market appearance. A moderate concentration of carbon dioxide slows the rate of change. A high concentration slows the rate of destruction of chlorophyll and to that extent delays ripening; however, this concentration also hastens the development of the dark yellow color, and the net effect is that it shortens the time when the lemons have an attractive light yellow color.

Oxygen concentrations as low as 5 percent were not injurious to lemons, but lemons stored in 3 percent oxygen sometimes failed to degreen completely during or after storage. This effect shows that the degreening mechanism was injured.

Purification of the atmosphere by passing it through a solution of perchloric acid and mercuric oxide delayed degreening, presumably by removing the ethylene, and improved the retention of citric acid. These effects were observed in lemons held in atmospheres containing above normal concentrations of carbon dioxide.

Lemons that were light yellow after storage contained more citric acid than dark yellow or orange-colored lemons held under the same storage conditions. The juice of lemons affected by rind blemishes contained lower concentrations of citric acid than the juice from light yellow fruit with sound rinds stored in the same container.

Lemons are bought and used principally for their flavor. The flavor is influenced by the acid content, but all lemons probably have enough acid to satisfy the consumer. The returns which the growers receive for lemons sent to processing plants are determined by the acid in pounds per ton of fruit. The returns for lemons that enter the fresh fruit market, however, are not based on acid content, and fruit with a high acid content does not necessarily bring more money than fruit with a low acid content.

Control of humidity is important in the CA (controlled atmosphere) storage of lemons. Commercially, lemons are successfully stored in air at 85 to 90 percent relative humidity. The uncontrolled relative humidity of the atmosphere in the CA chambers used in these tests approached saturation, and the fruit was often wet with water of condensation. This condition encourages the development of decay, and some of the lots suffered for this reason. Rotting fruit produces large amounts of carbon dioxide, making more difficult the maintenance of the desired atmospheric concentration. Rotting fruit also produces volatile metabolic products that may impart off-flavors or odors to the fruit.

The findings reported here give no assurance that the storage life of lemons can be increased by the use of CA storage. CA storage introduces too many possibilities of injuring the fruit and not enough likelihood of lengthening the storage life appreciably. Future investigations may disclose procedures that will make an extended storage life possible, but present information does not justify a recommendation of CA storage for lemons.

INTRODUCTION

Much experimental work has been done on the storage of various kinds of fruits in controlled atmospheres. Some of the findings have been applied commercially. Relatively little work of this kind has been done on citrus fruits. Barker (1, 2) held oranges in an atmosphere containing 20 percent carbon dioxide with unsatisfactory results.[1] Biale (4) determined the effect of various levels of oxygen and carbon dioxide on respiratory rates, degreening, and storage life of lemons. Brooks and others (5, 6) and Tomkins (10) investigated the effect of carbon dioxide on rind pitting, membranous stain, and decay in citrus fruits. Scholz, Johnson, and Buford (9) investigated the storage of red grapefruit in controlled atmospheres.

To obtain additional information on the response of lemons to storage in controlled atmospheres of various compositions, several 90- to 100-fruit lots were stored in atmospheres containing oxygen from 3 percent to that of normal air (about 21 percent) and carbon dioxide from 15 percent down to practically none. This study was part of a broad program of research to prevent undue deterioration and to prolong the life of fresh produce moving through marketing channels.

MATERIALS AND METHODS

Table 1 lists the source of the experimental fruit and the treatment given each lot. Dark green lemons grown near San Dimas, Calif., were used in the first test (lots 1 to 14). They were washed, dipped in 1:1,000 mercuric chloride, rinsed, and dried. Fifteen groups of 90 fruits each were prepared; 14 of these groups were stored. The remaining group was used for measuring total titratable acid before storage.

Dark green lemons grown in the interior desert area of California were used in the second test. They were washed in an aqueous soda ash solution at 115° to 120° F. and flooded with water wax containing 500 parts per million (p. p. m.) 2, 4-D. Seven groups of 100 fruits each were prepared; six of these were stored up to 31 weeks (lots 15 to 20), and one was used for prestorage analysis.

Light green lemons grown near San Dimas, Calif., were used in the third test. They were given the same packinghouse treatment as the fruits in the second test--washed in aqueous soda ash solution and flooded with water wax. Six 100-fruit lots were prepared; five of these were stored (lots 21 to 25), and one was used for prestorage analysis. The third test was terminated after 18 weeks because the storage facilities were closed for repair.

The atmosphere in the containers was modified by introducing suitable amounts of gas from cylinders of carbon dioxide, oxygen, or nitrogen, and adjusted at frequent intervals to maintain the desired composition. The containers were not swept with streams of artificial atmospheres; consequently, most of the volatile metabolic products remained in the system unless they were deliberately removed by absorption, as was done in some instances.

The lemons were stored at 56° F., a common commercial storage temperature.

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[1] Underlined numbers in parentheses refer to items in Literature Cited, page 11.

TABLE 1.--Source of fruit and storage conditions for test lots of lemons

Test, source, and lot No.	Atmospheric composition		Remarks
	Oxygen	Carbon dioxide	
	Percent	Percent	
Test 1; San Dimas, Calif.:			
1	21	Trace	Control; air circulated; fresh air constantly introduced
2	21	0	Air circulated in closed system; CO_2 absorbed
3	15	10	Controlled atmosphere circulated
4	15	5	Controlled atmosphere circulated
5	10	10	Controlled atmosphere circulated
6	10	5	Controlled atmosphere circulated
7	10	0	Controlled atmosphere circulated; CO_2 absorbed
8	5	10	Controlled atmosphere circulated
9	5	0	Controlled atmosphere circulated; CO_2 absorbed
10	15	10	Controlled atmosphere not circulated
11	15	5	Controlled atmosphere not circulated
12	10	10	Controlled atmosphere not circulated
13	10	5	Controlled atmosphere not circulated
14	10	0	Controlled atmosphere not circulated
Test 2; Thermal, Calif.:			
15	5	5	Controlled atmosphere not circulated; relative humidity about 88 percent
16	5	10	
17	5	15	
18	3	5	
19	3	10	
20	3	15	
Test 3; San Dimas, Calif.:			
21	21	Trace	Control; still air; commercial storage
22	3	5	Controlled atmosphere circulated through perchloric acid and mercuric oxide solution
23	3	5	
24	3	5	Controlled atmosphere circulated through glycerine solution
25	3	5	

Ethylene was removed from the atmosphere in the containers holding lots 22 and 23 of the third test by passing the atmosphere through a solution containing 60 percent perchloric acid and 5 percent red mercuric oxide (7).

No humidity control was attempted in the first test. In the second test the humidity of the atmospheres in the containers was lowered by placing in the containers trays containing saturated solutions of disodium phosphate with an excess of the salt. This treatment eliminated condensation on the inner walls of the containers.

In the third test the humidity was lowered to about 88 percent by circulating the atmosphere through a glycerine solution with a refractive index of 1.40.

Lots 1 and 2 in test 1 were held in air of normal oxygen and carbon dioxide concentrations. Fresh humidified air was passed through the container containing lot 1, to maintain an atmosphere of fresh normal air, whereas the air in the container containing lot 2 was recirculated within a closed system. Oxygen was added at frequent intervals to lot 2 to maintain the level of normal air, and the carbon dioxide was absorbed by a potassium hydroxide solution in a wide tray within the container. The volatile metabolic products other than carbon dioxide were allowed to accumulate in this container.

RESULTS

Effect of recirculating air.--More decay (table 2) developed during the 7-week holding period in the fruit that received a constant supply of fresh air (lot 1) than in the fruit in the container in which the metabolic products were retained (lot 2), but this difference

TABLE 2.--Decay in lemons stored in normal air and in controlled atmospheres, expressed in percentage of fruit stored, and average color of lemons after specified periods of storage

Test and lot No.	Atmospheric composition		Cumulative percentage of decay after storage for[1]--				Average color after storage for 5 weeks (test 1) or 22 weeks (test 2)[4]
	Oxygen	Carbon dioxide	4 weeks	7 weeks	22 weeks	33 weeks	
	Percent	Percent	Percent	Percent	Percent	Percent	
Test 1:							
1[2]........	21	Trace	11	16	--	--	Yellow
2[2]........	21	0	7	10	--	--	Yellow
3[2]........	15	10	4	9	--	--	Yellow
4[2]........	15	5	6	10	--	--	Yellow
5[2]........	10	10	3	3	--	--	Light green
6[2]........	10	5	13	24	--	--	Yellow
7[2]........	10	0	6	8	--	--	Yellow
8[2]........	5	10	0	1	--	--	Dark green
9[2]........	5	0	7	10	--	--	Yellow
10[3]........	15	10	3	3	--	--	Yellow
11[3]........	15	5	4	7	--	--	Yellow
12[3]........	10	10	2	3	--	--	Light green
13[3]........	10	5	0	0	--	--	Light green
14[3]........	10	0	1	1	--	--	Yellow
Test 2:							
15[3]........	5	5	--	--	0	0	Light yellow
16[3]........	5	10	--	--	0	4	Medium yellow
17[3]........	5	15	--	--	21	--	Dark yellow
18[3]........	3	5	--	--	0	2	Light yellow
19[3]........	3	10	--	--	0	7	Medium yellow
20[3]........	3	15	--	--	5	--	Dark yellow

[1] Decayed fruits were removed at each inspection. After 18 weeks in storage, none of the fruit in test 3 were decayed.

[2] With circulation of air in controlled atmosphere.

[3] Without circulation of air in controlled atmosphere.

[4] Lemons change successively from dark green to light green, silver, light yellow, and dark yellow or nearly orange. Dark yellow indicates senescence and detracts from the appearance of the lemons.

in decay probably is not significant. The citric acid content of the juice from each of the two lots was about the same (5.20 and 5.19 percent); the flavor was equally good in both lots of fruit at the end of storage.

Circulating the atmosphere in the CA (controlled atmosphere) containers in test 1 did not consistently influence the rate of yellowing (table 2). In this test the atmospheric composition was duplicated in the following five pairs: Lots 3 and 10, 4 and 11, 5 and 12, 6 and 13, and 7 and 14. Lots 3 to 9 were in circulating atmospheres and lots 10 to 14 in still atmospheres. The color of the fruit in both members of 4 of the 5 pairs was the same after 5 weeks; only lots 6 and 13 differed in color.

More fruit decayed in 7 weeks in the containers with circulating atmospheres than in the corresponding ones with still atmospheres in 4 of the 5 comparisons (table 2).

Effect of carbon dioxide.--High carbon dioxide combined with low oxygen concentration delayed degreening in test 1 (table 2). After 5 weeks' storage the fruit in 10 percent carbon dioxide and 5 percent oxygen (lot 8) was still dark green; fruit in 10 percent carbon dioxide and 10 percent oxygen (lots 5 and 12) was light green; and fruit in 10 percent carbon dioxide and 15 percent oxygen (lots 3 and 10) was yellow. All fruits in 5 percent carbon dioxide, except those in lot 13, and all fruits in atmospheres with no carbon dioxide or only a trace were yellow regardless of oxygen concentration. Slowing the degreening process is desirable when the longest possible storage life is sought.

After prolonged storage some of the lemons stored in higher concentrations of carbon dioxide developed a deeper yellow color than those in lower concentrations. This association of high carbon dioxide concentration and deep yellow color development was first noted in lots 8 and 13 of the first test. The small amount of decay in these lots permitted them to be stored longer than the other lots in this test. After 16 weeks the average color of the fruit in lot 8, held in 10 percent carbon dioxide and 5 percent oxygen, was noticeably darker yellow than that in lot 13, held in 5 percent carbon dioxide and 10 percent oxygen. The difference in oxygen concentrations for these two lots did not produce the difference in color, for the same effect of carbon dioxide concentration was observed in test 2 in lots in which the oxygen concentration was uniform (lots 15-17 and 18-20). In this test lots 15, 16, and 17 were held in 5 percent oxygen, but lot 15 was in 5 percent carbon dioxide, lot 16 in 10 percent carbon dioxide, and lot 17 in 15 percent carbon dioxide. Similarly, lots 18 to 20 were in 3 percent oxygen, and the carbon dioxide concentrations were 5 percent for lot 18, 10 for lot 19, and 15 for lot 20. After 22 weeks' storage the average color of the fruit in lots 17 and 20 was noticeably darker yellow than that in the other lots exposed to the same oxygen concentration. The average color of the fruit in lots 16 and 19 was intermediate (table 2).

In addition to inducing the development of a deeper than normal yellow color in the rind, a carbon dioxide concentration of 15 percent injured the rind of fruit in test 2. Some of the fruit in each lot was held in air at 68° F. for 3 weeks after removal from the CA containers. Severe rind breakdown developed in fruit in lots 17 and 20, but none in the other lots. No such holding tests were conducted in test 1.

Some workers (4, 9, 10) have reported that a high carbon dioxide concentration in the storage atmosphere increases the tendency for citrus fruit to decay. Others (5) found that a short exposure to a high carbon dioxide concentration suppressed fungal development. The effects of carbon dioxide on decay were not consistent in the tests reported here. In the second test more decay developed in 22 weeks in fruit held in 15 percent carbon dioxide and 5 percent oxygen than in fruit held at 5 or 10 percent carbon dioxide and 5 percent oxygen (table 2). The differences were not so great when the oxygen concentration was reduced to 3 percent. Storage in 15 percent carbon dioxide was discontinued after 22 weeks because of the large amount of decay. The first test did not show any relationship between carbon dioxide concentration and decay; no decay developed in any lot in the third test.

No level of carbon dioxide that was used prevented Penicillium from sporulating.

The citric acid concentration was lower in the juice from lemons stored in atmospheres with 5 percent or more carbon dioxide than in those stored in normal air (table 3). For example, in test 1 five lots of fruit (lots 1, 2, 7, 9, and 14) held for 7 weeks in carbon dioxide free atmospheres had an average citric acid concentration of 5.11 percent and 7 lots (lots 3, 4, 5, 6, 10, 11, and 12) held in atmospheres with 5 or 10 percent carbon dioxide had an average acid concentration of 4.73 percent. Concentrations of 5 and 10 percent carbon dioxide produced about equal effects on the acid concentration during 7 weeks' storage.

TABLE 3.--Citric acid in the juice of stored lemons

Test and lot No.	Oxygen	Carbon dioxide	After indicated number of weeks in storage			
			7	18	22	31
	Percent	Percent	Percent	Percent	Percent	Percent
Test 1:						
1	21	Trace	5.20	--	--	--
2	21	0	5.19	--	--	--
3	15	10	4.99	--	--	--
4	15	5	4.58	--	--	--
5	10	10	4.77	--	--	--
6	10	5	4.67	--	--	--
7	10	0	5.13	--	--	--
9	5	0	4.99	--	--	--
10	15	10	4.54	--	--	--
11	15	5	4.81	--	--	--
12	10	10	4.73	--	--	--
14	10	0	5.05	--	--	--
Test 2:[1]						
15	5	5	--	--	--	5.05
16	5	10	--	--	--	4.49
17	5	15	--	--	4.55	--
18	3	5	--	--	--	4.69
19	3	10	--	--	--	4.68
20	3	15	--	--	4.52	--
Test 3:[1]						
21	21	Trace	--	6.54	--	--
22	3	5	--	5.97	--	--
23	3	5	--	6.36	--	--
24	3	5	--	5.24	--	--
25	3	5	--	5.46	--	--

[1] Sound light yellow fruit only.

Low levels of carbon dioxide did not produce noticeable off-flavor or odor, but the flavor was flat after storage at concentrations of 10 percent or higher. The effect was greater at 15 percent than at 10 percent.

Effect of low oxygen.--Oxygen concentrations as low as 5 percent did not affect degreening adversely, but in test 3 a little green color remained at the end of 5 months' storage in 3 percent oxygen and 5 percent carbon dioxide. This color still remained after an additional period of 3 weeks in normal air at 75° F. Biale (4) reported a similar effect at 2.5 percent oxygen. No level of oxygen concentration used prevented *Penicillium* sporulation.

Lemons stored in oxygen concentrations of 5 or 10 percent contained slightly less citric acid than those stored in normal air (table 3). For example, after 7 weeks' storage, two lots of lemons in air with a normal oxygen concentration (lots 1 and 2) contained an average of 5.20 percent acid, whereas three lots of lemons held in atmospheres containing 5 or 10 percent oxygen and no carbon dioxide (lots 7, 9, and 14) contained from 4.99 to 5.13 percent (table 3). This small difference may not be significant. A high citric acid content is advantageous to the grower when the lemons are sold to processors. Payment is based on the amount of citric acid per ton of fruit. Citric acid does not directly affect the returns paid the grower for lemons marketed as whole fruit.

The flavor and odor of lemons were not affected by any concentration of oxygen used in these tests.

Effect of air purification.--Sound lemons produce little if any ethylene. However, green mold and several other rot-producing organisms produce considerable quantities of ethylene when growing on lemons or in culture dishes (3, 4, 8). Biale emphasized the desirability of removing this and other volatile metabolic products.

Four lots of 100 lemons each were held in 3 percent oxygen and 5 percent carbon dioxide for 18 weeks in test No. 3. The atmospheres in two containers were bubbled through a perchloric acid-red mercuric oxide solution, and the atmospheres in the remaining two containers were allowed to retain the volatile fruit emanations. After 18 weeks, 25 percent of the fruit in each of the two lots held in the unpurified atmosphere were fully yellow in color, whereas only 11 and 14 percent of the fruit in the lots from which the ethylene had been removed were fully colored (table 4).

TABLE 4.--Effect of air purification on degreening of lemons in test No. 3 after 18 weeks in storage

Air purification and lot number	Color of fruit after storage		
	Yellow	Silver	Light green
	Percent	Percent	Percent
Normal air:			
21	100	0	0
Air purified:[1]			
22	14	41	45
23	11	50	39
Air not purified:[1]			
24	25	52	23
25	25	50	25

[1] 3 percent oxygen and 5 percent carbon dioxide.

Air purification improved the retention of citric acid. After 18 weeks' storage the juice of light yellow lemons held in purified air in test 3 (lots 22 and 23) contained an average of 6.17 percent acid, whereas similar lemons held in nonpurified atmosphere of the same oxygen and carbon dioxide content (lots 24 and 25) contained 5.35 percent (table 3).

Association of external appearance with acid content.--Lemons that turned dark yellow to orange in color while in storage contained less citric acid than those that retained good light yellow rind color when stored in the same container. This relationship was not investigated in the first test. In the second and third tests, however, the lemons were separated into groups of light yellow and dark yellow or orange-colored fruit after storage. The juice of light-colored fruit consistently contained a higher concentration of citric acid than the juice of the dark-colored fruit (table 5).

TABLE 5.--Relationship of citric acid content of juice to rind condition or color

Test and lot No.	Sound rind		Blemished rind
	Pale yellow or light green	Dark yellow or orange	
	Percent	Percent	Percent
Test 2:			
15	5.05	4.40	4.50
16	4.49	3.44	3.45
17	4.55	--	4.29
18	4.69	4.10	4.57
19	4.68	3.97	4.23
20	4.52	--	4.30
Test 3:			
21	6.54	5.90	--
22	5.97	5.39	--
23	6.36	5.42	--
24	5.24	4.75	--
25	5.46	4.85	--

Both light yellow and dark yellow lemons sometimes developed mild to severe rind blemishes while stored in controlled atmospheres. These appeared to be symptoms of physiological disturbances, for no pathological organisms were found to be associated with the disorder. The blemishes consisted of irregular brown or green discolored and slightly depressed areas, and were similar to oleocellosis. The juice of lemons injured in this manner contained less citric acid than sound light-colored fruit stored in the same container for the same length of time, but not less than dark yellow or orange-colored lemons (table 5). The blemished lemons were analyzed as a group and were not sorted for color.

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